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Program Element Title: Retrospective analysis of long-term benthic community data

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I. Program Element Management

A. Program Element Description/ Problem Definition

1. History or Background -

Benthic organisms are the interface between the bottom substrate of aquatic habitats and overlying pelagic communities, and thus are often used as biological indicators of the quality and quantity of aquatic habitat (Pearson and Rosenberg, 1978; Levin et al., 1994; Levin and Gage, 1998; Sibuet et al., 1989; Cosson-Seradin et al., 1998). Due to their relative site-fidelity (most benthic organisms can not move once they become established on the bottom), individuals in the benthic community are selected by the numerous physical, chemical, and biological factors that characterize the environment in which they live. Variations in the structure of benthic communities reflect both environmental changes over time and environmental gradients in space (Zajac and Whitlatch, 2001; Ricciardi and Bourget, 1999), and thus they are often used to measure the impact of disturbance or pollution in aquatic systems (Warwick and Clarke, 1993; Agard et al., 1993). In turn, changes in the composition or structure of the benthic community may cause changes in the ecological function of the benthos. For instance, at high densities suspension-feeding organisms have the ability to overgraze a system (Officer et al., 1982; Nichols, 1985; Alpine and Cloern, 1992), sequestering suspended organic matter at the bottom, away from overlying pelagic food webs. Benthic organisms play an important role in the biogeochemical cycling of elements such as nutrients and contaminants between bottom sediments and pelagic habitats. Benthic organisms influence the cycling these elements through bioturbation of the substrate, remineralization of nutrients, and by becoming prey for higher trophic levels (including benthivorous fish and birds).

The design of IEP's Environmental Monitoring Program (EMP), and in particular its benthic monitoring component, was proposed by Stanford Research Institute (SRI) in 1970. The EMP was created in response to Water Right Decision 1379, which provided terms and conditions for a comprehensive monitoring program to routinely determine water quality conditions, pollutant loads, sources, and changes in environmental conditions within the estuary. The benthos was one of several biotic components included in the environmental program because of its sensitivity to environmental change. Originally, the benthic monitoring component was included to monitor potential salinity intrusions due to project operations and hydrologic variability, and as an indicator of eutrophication, which was expected as a result of agricultural development and urbanization in and around the estuary.

Since the 1970's our ability to monitor aquatic environments and our understanding of biological and ecological processes within the estuary have advanced tremendously. Technological advances have made it cost effective to monitor salinity and other chemical conditions directly within aquatic habitats with accuracy. Scientific studies have established and documented the importance of the role played by the benthos on the ecological processes of estuarine habitats. Current examples of the importance of benthic-pelagic coupling in the San Franciso estuary include the disappearance of the annual phytoplankton bloom since the introduction of *Potamocorbula amurensis* in 1986 (Alpine and Cloern, 1992); the resultant decline in the Mysid shrimp, *Neomysis mercedis* due to food limitation (Orsi and Mecum, 1996); and the reduction in populations of some copepod species due to food limitation and predation by *P. amurensis* (Kimmerer et al, 1994). In turn, the decline in copepods abundance may be furthering the decline of some of the top predators in the food chain, including the striped bass (Kimmerer et al 2000) and other fish. While scientific understanding of the role of the benthos in the estuarine ecosystem has developed remarkably over the past 30 years, IEP's benthic monitoring component has remained largely unchanged. The changing ecological paradigm has fostered new needs for data and information about benthic communities and their role in assessing the impact of project operations in the San Francisco Estuary.

In the recent review of the EMP by IEP staff and the IEP Science Advisory Group (SAG), both groups recognized the need to undertake a critical review of the present benthic sampling design. The SAG specifically suggested that a comprehensive evaluation of existing benthic and accompanying ancillary data is necessary to guide the direction and scope of benthos monitoring efforts. We propose conducting a retrospective analysis of data from four long-term (1977-present) benthic monitoring sites to uncover the historical trends in community composition in relation to environmental variability, hydrology, and exotic species invasions. This retrospective analysis will be the first look at these data from a process perspective, exploring how environmental variability within the estuary has influenced the composition of the benthic community and how changes in the benthic community over time may affect the estuarine ecosystem. Results of this study will be applied in the decision making and planning process for the next iteration of the IEP EMP review.

2. Purpose of program element in explicit terms
    a. Questions to be answered.

1) What are the benthic community assemblages at core sites (D4 near Collinsville, including left, right and center sampling locations, D28A in Old River including left and right sampling locations, D7 in Grizzly Bay, and D41A in San Pablo Bay)?
2) Does the community assemblage at each location vary predictably with environmental factors? Has the relationship between environmental factors and assemblage changed over time?
3) Is the variability in community assemblage predictable among cross-channel locations?
4) Is the variability in community assemblage predictable among sites up or down the axis of the estuary?

5) What are the past, present and potential ecosystem responses to changes in the benthic community over the sampling period?

b. Objectives of the program element.

1) Identify recurring taxa assemblages within the benthic community at core EMP benthic monitoring sites.
2) Determine the predictable relationships between taxa assemblages and environmental conditions and/or species invasions, including evaluation of physical chemical conditions as factors limiting the distribution of benthic fauna and physical chemical conditions as independent response variables to biological change (e.g., reduction in chlorophyll concentrations contemporaneous with high filter-feeder biomass).
3) Define the habitat at each site as a function of environmental conditions, season and year.
4) Describe community function over the course of the historical sampling period using the results of taxa assemblage analyses, records of species natural histories including feeding and reproductive group as well as life position in the substrate from peer-reviewed scientific literature and “Bio-Vault” sister proposal (Messer et al., 2002), and species biomass data from sister proposal Gehrts et al (2002) measuring benthic biomass. Use these descriptions to determine where and when benthic assemblages capable of having significant effects on bio-geo-chemical cycling of nutrients and trace elements have been present (e.g., where and when have filter-feeders been abundant enough to limit food to other populations, and where and when might changes in benthic assemblages have effected trace element transport or patterns of predation for higher trophic levels?).
5) Refinement of methodology for analysis of IEP EMP data. Success in this project might suggest ways in which methods used here may be applied to analysis of other IEP EMP biological monitoring data. Results and conclusions from this study may suggest appropriate questions for the monitoring program to address, and lend *a priori* knowledge of how the information will be analyzed that will help structure future design of the benthic monitoring program.

c. How will success be determined?

1) Taxa assemblages defined and described as a function of environmental conditions and time at each site, community function described over historical sampling period.
2) Reporting the objectives listed above to the IEP and estuarine scientific community (see deliverables described below)
3) Production of a final report in the form of a peer-reviewed publication.

3. How will data and information from program element be used?

1) It is expected that the results of this study will be used by the IEP for program assessment, future program design, and as a means of connecting processes related to the benthos with other biotic communities, especially higher trophic levels.
2) Results of this study should lead to the formation testable hypotheses, which may be the focus of future special studies.
3) Results of this study will be used to demonstrate methodology for future analysis of IEP monitoring data.

4. What are the biological implications of the program element?

1) This element should provide an initial means of connecting variability in the benthic community with estuarine processes over the historical study period.

B. **Project Resource Needs:**

	USGS I Peterson		USGS II Thompson		DWR/CALFED Vayssières		Two year total
Year	2004	2005	2004	2005	2004	2005	
Salary	$40,193	$40,193	$4,897	$5,166	($35,000)*	($35,000)*	$90,499
Benefits	$24,116	$24,116	$1,469	$1,550			$51,251
Indirect Costs	$57,476	$57,476	$3,501	$3,694			$122,147
Travel	(IEP&Sacto) $800	$800					$1,600
Misc	Computer: $2,000	Publication costs: $1,000					$3,000
Total	$124,585	$123,585	$9,867	$10,410	($35,000)*	($35,000)*	**$268,447**

* Salary for Marc Vayssières will be covered by DWR CalFed Science Program and not funded by IEP monies allocated for this study.

C. **ESA Considerations (Not applicable)**

D. **Due Dates and Products**

We envision this as a two-year project with a start date of January 2004. In the first year we will develop available data and run preliminary exploratory analyses. In the second year we will analyze results and document the findings. During the study, progress reports and discussions of findings will be shared with the IEP Benthic Estuarine Ecology Team (BEET) and EET working groups at regular meetings.

Deliverables will include an IEP newsletter report each summer, and a final report in the form of a peer-reviewed publication submitted to an appropriate publication by December 2005. Preliminary results will be presented in poster form at the IEP conference in spring 2005. Results will be presented at the IEP conference in spring 2006. Results will also be relayed back to the IEP EMP program heads for use in reassessment of the IEP EMP benthic monitoring program.

II. Program Element Measurement and Data Acquisition

A. Sample Site Selection

1. Brief description of study area and list of sample sites

Sites D7 (Grizzly Bay), D4 (Collinsville), and D28A (Old River) are the IEP EMP benthic monitoring sites with the longest continuous sampling records, spanning 1977 - present. Site D41A (San Pablo Bay) has been sampled by the IEP EMP since July 1991, but data from regular monitoring conducted by the USGS and the Regional Effects Monitoring Program in 1976, 1977, 1986 – June 1991 were included in ongoing community analysis at this site (Thompson and Peterson, expected spring 2003). These sites are located along the axis of the estuary spanning the brackish to freshwater habitats and representing shallow embayments as well as cross-channel locations. Preliminary analyses show that there is some overlap in benthic community composition between adjacent stations, indicating continuity in the benthic assemblages along the axis of the estuary. See figure 1 for a map of the study area.

B. Sampling Procedures

At each station, three or four samples were taken by boat with a Ponar grab, which samples a bottom area of 0.053 m2. Samples were then washed through a Standard No. 30 stainless steel mesh screen (0.595 mm openings). All material remaining on the screen after washing was preserved in approximately 20% buffered formaldehyde containing Rose Bengal dye. In the laboratory, benthic macro-invertebrates were sorted from each sample, identified to lowest possible taxon (species where possible), counted, and preserved in 70% ethanol. Samples were analyzed by Hydrozoology, Newcastle, California, for the entire period of record. **(**for details see http://iep.water.ca.gov/metadata/DBMS/D1485/d1485_bent.html**)**

C. Sources of available historic data used in the analyses

Variable	Frequency	Citation	Data Type	Conditioning
Benthic Community Abundance	Semi-annually 1977-1979 Monthly Jun1980-Dec 2000	IEP Water Quality Monitoring Program http://www.iep.ca.gov/data.html	Organism Count	Monthly average abundance for each taxon per 0.053 m^2 grab from 3 replicate samples per month1977-1995, 4 replicate samples per month 1996-2000
Sediment grain size and organic content	Semi-annually 1977-1979 Monthly Jun1980-Dec 2000	IEP Water Quality Monitoring Program	Sediment grain size and organic content	Single monthly samples taken during community sampling (above)
Discrete Water Quality	Monthly or twice monthly	IEP Water Quality Monitoring Program http://www.iep.ca.gov/data.html	Water temperature °C, turbidity NTU, Secchi depth, Conductivity corrected to25 °C µS, dissolved solids, suspended solids, volatile suspended solids, Chlorophyll *a* $\mu g\ l^{-1}$	Monthly average values from monthly and twice-monthly monitoring data
Salinity time series	Daily means	IEP Water Quality Monitoring Program http://www.iep.ca.gov/data.html	Conductivity corrected to 25 °C µS	Conductivity converted to salinity (psu) (Lewis ,1980) using simplified equation (Schemel, 2001).
Temperature time series	Daily means	IEP Water Quality Monitoring Program http://www.iep.ca.gov/data.html	Water temperature °C	Daily data used to compute monthly means
Water flow	Daily	IEP Dayflow Program http://www.iep.ca.gov/dayflow/index.html	Calculated net (tidally averaged) flows within the Delta and Delta outflow.	Daily values were used to compute monthly mean outflow
Weather Station Data	Daily average values	California Irrigation Management Information System (CIMIS) weather station data via Integrated Pest Management website at UC Davis http://www.ipm.ucdavis.edu/WEATHER	Precipitation, air temperature, wind speed, wind direction, and solar radiation	Daily values were used to compute monthly mean
X_2	Monthly	Jassby et al, 1995 data from W. Kimmerer, Personal Communication, Kimmerer, 2002	Km X_2 (2psu isohaline) from Golden Gate	None

D. Data Reduction, Analysis and Reporting

Analysis of IEP EMP core sites D4 (Collinsville) and D28A (Old River) proposed for this study will be combined with pre-existing analyses from D7 (Grizzly Bay) (Peterson, 2002) and D41A (San Pablo Bay) (Thompson and Peterson, expected spring 2003). See figure 2 and 3 for examples of these pre-existing analyses. Ancillary environmental variables are listed in the table above. Analytical methods will include classical methods and modern methods from the statistical and ecological literature. Classical methods include data visualization techniques (Cleveland, 1993), regression analysis, cluster analysis (see Peterson, 2001), indexes of community diversity, and analysis of functional group, which have been successfully applied in Peterson (2002) and Thompson and Peterson (expected 2003). In addition this study will use Classification and Regression Trees (CART), a powerful set of non-parametric methods (Breiman et al. 1984) used successfully by Vayssières et al. (2000) and others (De'ath and Fabricius, 2000) to predict species distributions from environmental data. Vayssières et al. (2000) have shown that CART models often performed significantly better than polynomial logistic regression models for modeling individual species-environment relationships. CART also showed a superior ability to detect factor interactions within the environmental variables. Insight gained from the CART models then helped develop improved parametric models. Deáth and Fabricius (2000) have used CART to analyze survey data from the Australian Great Barrier Reef, comprising abundances of soft coral taxa and physical and spatial environmental information. Regression tree analyses showed that dense aggregations, typically formed by three taxa, were restricted to distinct habitat types, each of which defined by combinations of 3 to 4 environmental variables. We will also use Multivariate Regression Trees (MRT, De'ath, 2002), a powerful statistical technique for modeling species communities – environment relationships. De'ath (2002) has shown that MRT compared favorably to redundancy analysis and canonical correspondence analysis using simulated data and field data sets.

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IEP benthos data base: http://sarabande.water.ca.gov:8000/~bdtdb/dwr1.html

IEP EMP SAG review document available through http://www.iep.ca.gov/emp

Appendices

Figure 1: Map of Study Area

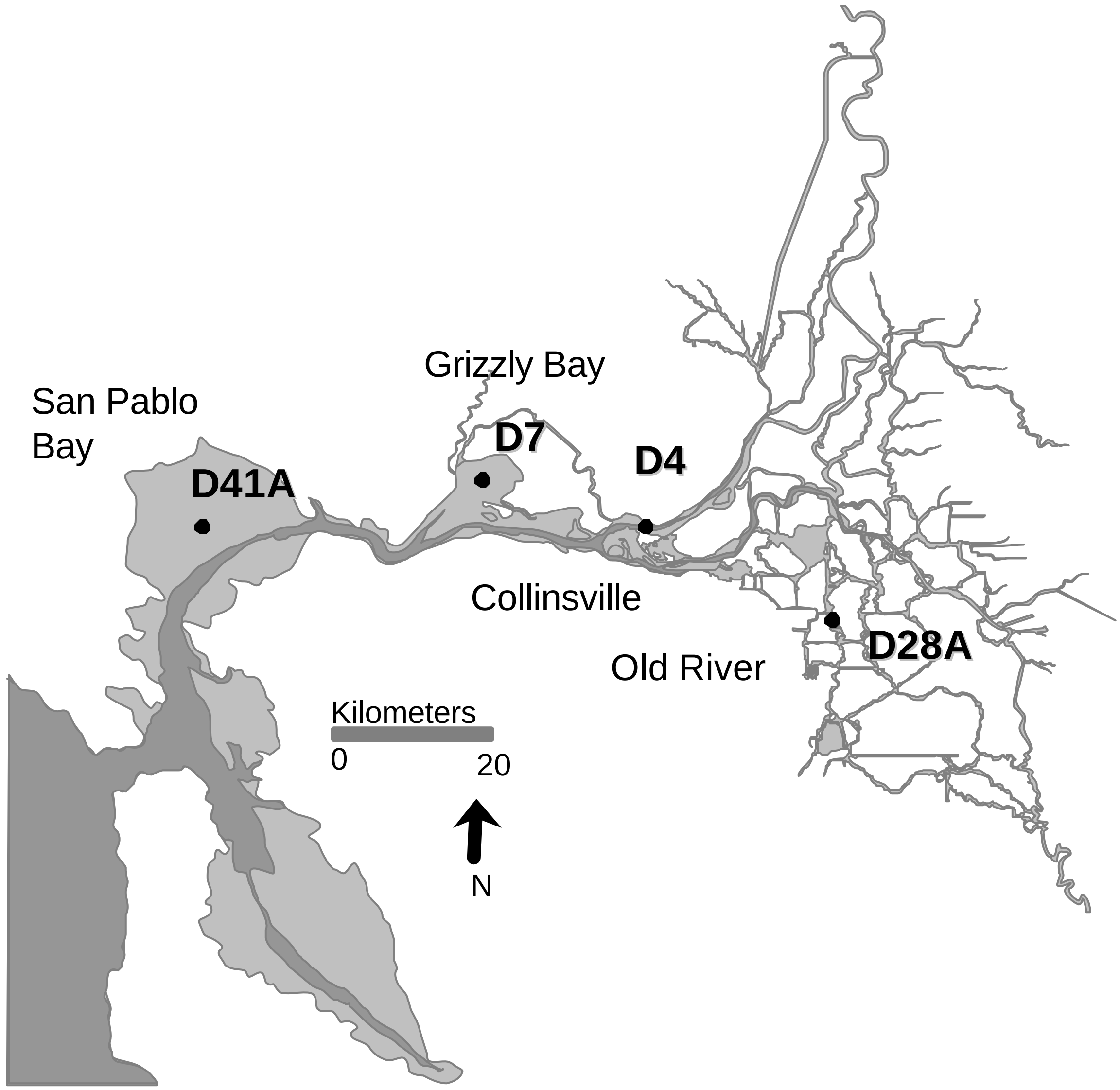
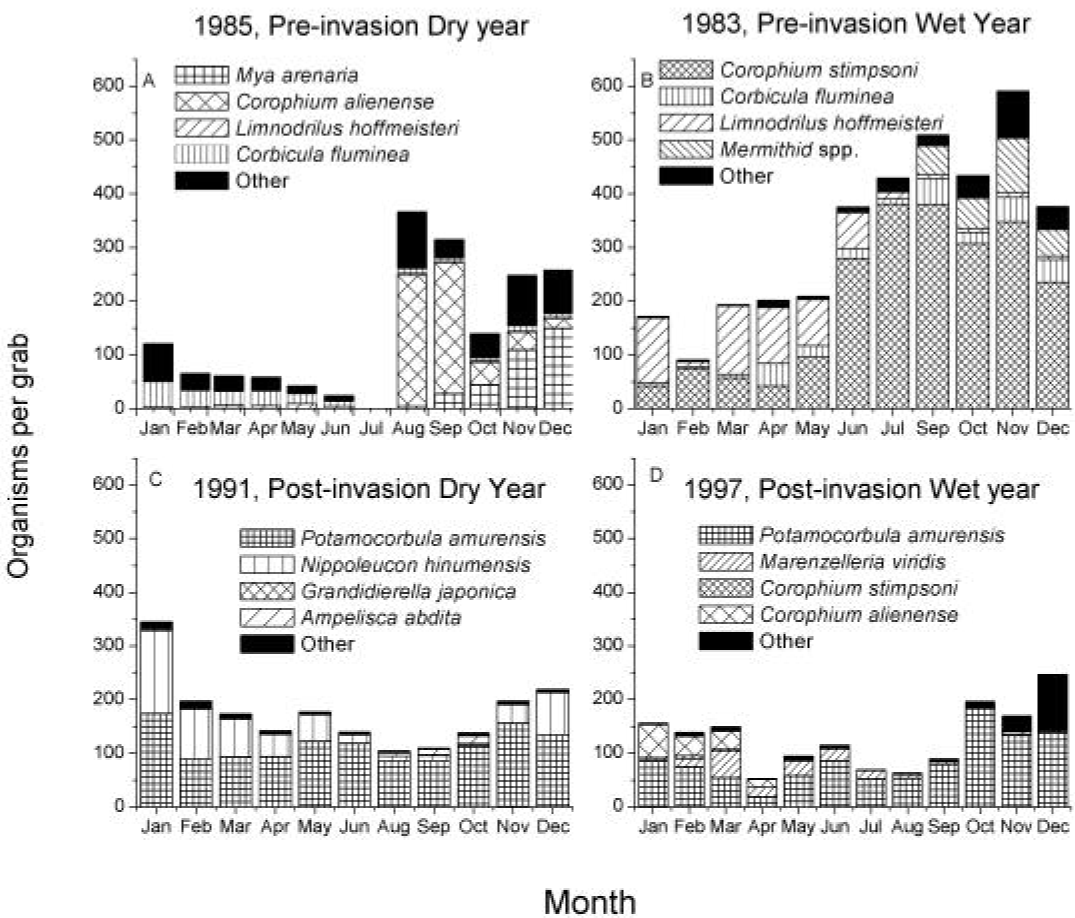


Figure 2: Benthic community composition in Grizzly Bay was most predictable in ‘wet’ or ‘dry’ hydrologic year types (Peterson, 2002). After the invasion of the bivalve *Potamocorbula amurensis* in 1986, community assemblages were discernable between wet and dry years, but post-invasion assemblages were different from those seen prior to the invasion. Here, Grizzly Bay benthic community composition in dry (A, 1985) and wet (B, 1983) years before the *Potamocorbula amurensis* invasion and dry (C, 1991) and wet (D, 1997) years after the *Potamocorbula amurensis* invasion are examples of recurring patterns of community composition and abundance in wet and dry years pre and post-*P. amurensis* invasion. Year type classifications are according to Peterson et al. (1985)



1985, Pre-invasion Dry year
A
Mya arenaria
Corophium alienense
Limnodrilus hoffmeisteri
Corbicula fluminea
Other
1983, Pre-invasion Wet Year
B
Corophium stimpsoni
Corbicula fluminea
Limnodrilus hoffmeisteri
Mermithid spp.
Other
C
1991, Post-invasion Dry Year
Potamocorbula amurensis
Nippoleucon hinumensis
Grandidierella japonica
Ampelisca abdita
Other
D
1997, Post-invasion Wet year
Potamocorbula amurensis
Marenzelleria viridis
Corophium stimpsoni
Corophium alienense
Other
Organisms per grab
Month

Figure 3: Trends in estimated biomass by feeding functional group from analysis of IEP EMP benthic monitoring site D7 in Grizzly Bay (Peterson, 2002) show that the Grizzly Bay benthic community is intermittently dominated by suspension feeders until the invasion of *Potamocorbula amurensis*. Once *P. amurensis* (a suspension feeder) is established in the Grizzly Bay benthic community its biomass remains high inter-annually. Peaks in suspension feeder abundance (related to biomass) have been associated with low chlorophyll *a* concentrations in the water column (Alpine and Cloern, 1992).